Sources of Variations in the Cosmic-Ray Flux and Astrobiological Consequences

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It has been repeatedly suggested that variations in the cosmic-ray (CR) flux have affected terrestrial atmospheric chemistry, climate, and evolution, either by solar CR variations, passage of the solar system through interstellar clouds, or variations in the star formation rate during the Sun's orbit around the Galaxy. The present work gives a detailed estimate of amplitudes, timing, and durations of such variation in the CR flux and spectrum on terrestrial-like planets orbiting stars of different ages, masses, and Galactic locations. Planetary magnetospheric screening is included using empirically-determined terrestrial magnetic field variation statistics for illustration. Several sources of CR variation over a variety of timescales have been investigated: 1. Variation in screening of lower-energy CRs as the astrosphere (analogue of heliosphere) expands and contracts during passage through the strongly fluctuating density and velocity field of the interstellar medium. Statistics for cosmic ray fluxes were accumulated using nearly a million planetary system trajectories through model clouds. The calculations use a convection-diffusion model for CR screening, a pressure balance model for the astrosphere size, and a 3D MHD simulation of the interstellar medium to realistically capture the crucial density, velocity, and magnetic field variations. 2. A new source of CR flux variation that should affect all planetary systems, intrinsic to CR propagation through the ISM, was discovered. The resulting CR flux should vary by one to two orders of magnitude in the interstellar medium for CR energies less than about 10-100 GeV. The passage of planetary systems through the ISM accounting for this effect was studied and the statistical properties of the resulting CR fluxes compared to the astrospheric variations. 3. Spatial and temporal variations in the CR flux will arise due to the clumpy distribution of star formation sites, as well as their preference for spiral arms. These variations have been estimated and compared with the other sources listed above. 4. A self-consistent comparison of the history of solar and Galactic CRs indicates that during the first 1-3 Gyr of the Earth's history solar CRs were more important in terms of total flux. The Earth is presently near a time of minimum average CR flux: the increasing Galactic component has only recently overtaken the waning solar component. Arguments are given that a modestly enhanced CR flux would contribute significantly to the exogenous and total DNA damage and mutation rate. Population genetics models with stochastic mutation rates and selection coefficients are used to examine the effects on genomic diversity and specific problems like mutation fixation timescales.